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Detecting cumulus clouds in satellite images using image processing techniques:- a preliminary study.

by

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ABSTRACT

A scheme is presented that uses a cross-correlation technique to detect cloud elements of a certain shape and size. The ability of this scheme to detect large cumulus clouds in an infrared Meteosat image is demonstrated.

A second scheme is presented that uses a graph technique to analyse and delineate areas characterised by the spatial distribution of particular cloud elements detected using the first method. The second scheme has been used to detect areas in which small cumulus clouds have formed.

Both schemes would require careful tuning to the needs of real applications before being used operationally. Some areas in which more work would be needed are indicated.

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1 Abstract

A scheme is presented that uses a cross-correlation method to detect cloud elements of a certain shape and size. The ability of this scheme to detect large cumulus clouds in an infrared Meteosat image is demonstrated.

A second scheme is presented that uses a graph technique to analyse and delineate areas characterised by the spatial distribution of particular cloud elements detected using the first scheme. This scheme has been used to detect areas in which small cumulus clouds have formed.

Both schemes would require careful tuning to the needs of real applications before being used operationally. Some areas in which more work would be needed are indicated.

2 Introduction

For many years, meteorological analysts have used satellite imagery to assist them in their task of providing a description of weather systems, usually as a precursor to generating weather forecasts. During the recent past, computer systems have become more powerful and more freely available, the amount of satellite imagery data has increased and the availability of skilled analysts has decreased. Consequently, it has become more common to use automatic techniques for detecting clouds, instead of a manual analysis. Very often, however, the automatic algorithms used so far focus their searches for cloudy pixels on small sub-areas of an image. Whereas a number of the algorithms use multi-spectral information over that small area (see for example Saunders and Kriebel (1988), Karlsson (1989), Derrien et al (1993)), they do not attempt to analyse broad-scale structures in the way that it seems likely that human analysts do. Hence, their potential for detecting particular forms of clouds seems somewhat limited. This paper reports a preliminary study to identify individual cumulus clouds in satellite imagery from the characteristics of their large-scale appearance in the images. A related problem, namely the identification of areas in which convective activity was occuring, was also studied.

It was decided to perform this study using convective clouds for two reasons. Firstly, they are of potential importance to customers of weather forecasts of such clouds - cumulonimbus are associated with severe turbulence, severe icing, extremely poor visibility, heavy precipitation and thunderstorms, all of which can be serious hazards to many types of transport. Secondly, the large-scale appearance of such clouds in satellite images is well known, simplifying the task of testing and validating the algorithms.

The demonstration programs were written in PV-WAVE, a high-level image processing and

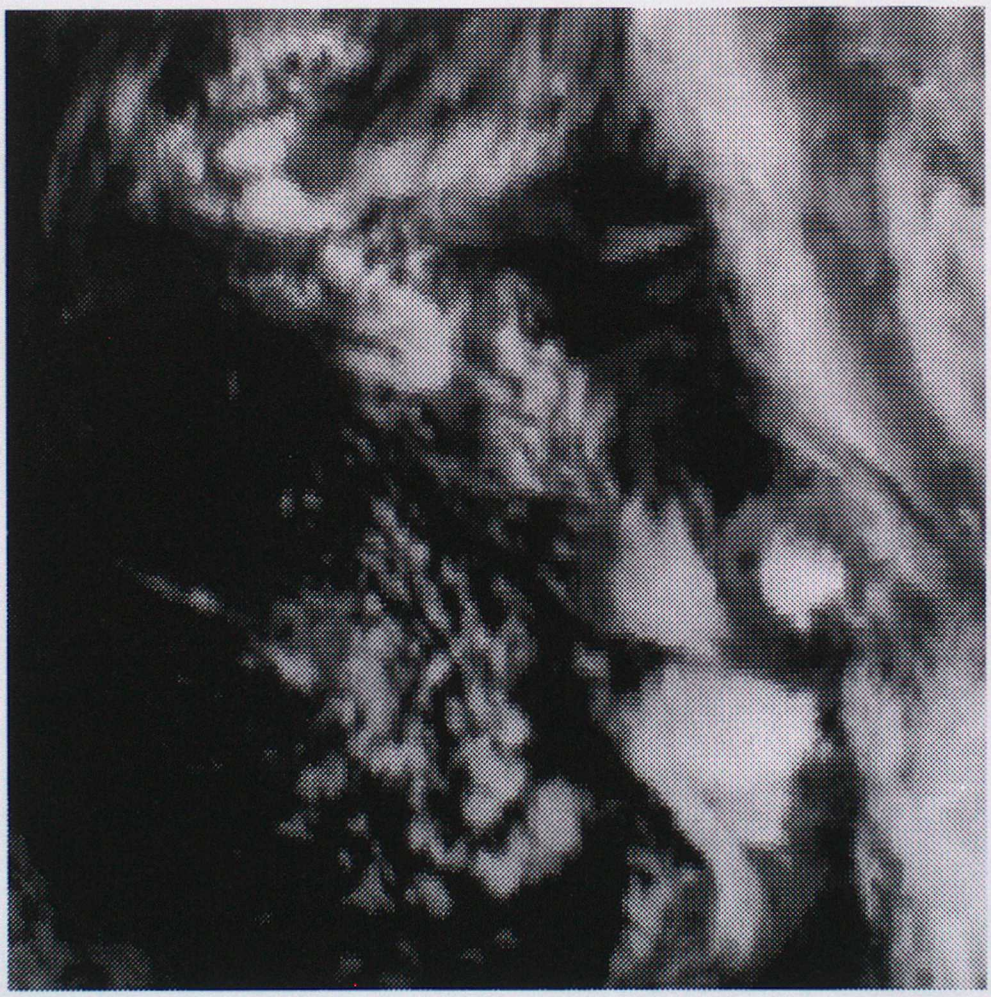
mathematical analysis package provided by Visual Numerics. The language provides many intrinsic mathematical functions which made the process of algorithm development much more efficient than would have been possible if FORTRAN had been used.

3 Principle of the cumulus detection method

3.1 Pre-processing of the satellite images

The principle of the scheme is to search a satellite infra-red image for shapes that are characteristic of convective clouds. Infra-red images were used to ensure a maximum applicability during the day. It would be advantageous to look for characteristic shapes in a field of cloud already diagnosed using a multi-spectral scheme. At the time of writing, no such scheme was available for application to the Meteosat data used (see figure 1).

Figure 1 - Meteosat IR image



Instead, a simple slicing algorithm was used in the expectation that only the coldest of clouds would be characteristic of meteorologically significant cumuliform clouds. The first part of the process is, therefore, to generate an image containing "cold clouds" and "no cold clouds" (see figure 2).

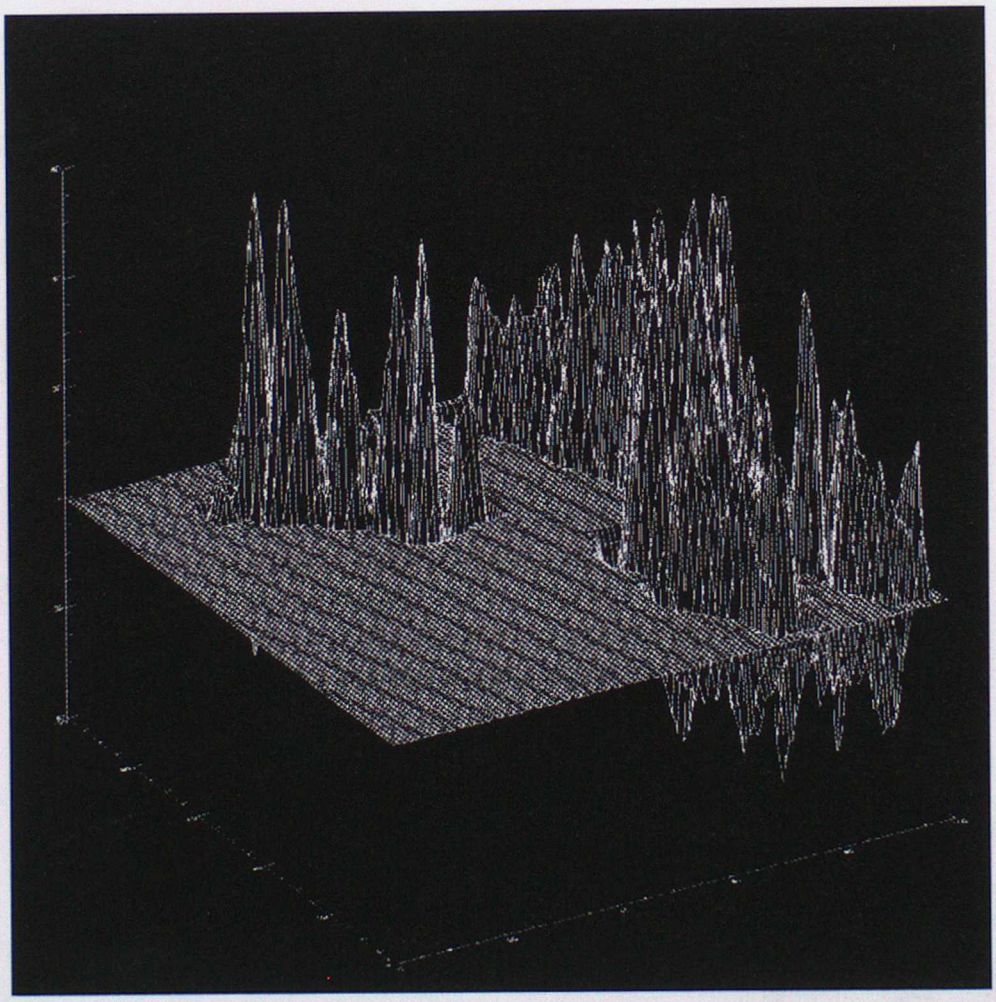
Figure 2 - Sliced Meteosat IR image

3.2 Generating the correlation surface

The next stage is to search for shapes in the sliced image that are characteristic of cumuliform cloud. A characteristic "round" shape with a particular diameter is defined for use as a template. The template is moved over the sliced image and the correlation between the two shapes computed. Where the part of the image is similar to that of the template (and hence of the desired cloud), the correlation is high: where the part of the image is dissimilar to the template (and hence to the cloud), the correlation is low.

In principle, the correlation should be computed for all possible positions of the template in the image. However, the correlation calculation can be rather time-consuming. Often, the cross-correlation between the image and the chosen template is computed for a sample of positions: intermediate values are obtained by bi-linear interpolation. In practice, however, it was found to be much more efficient computationally to use the convolution function[1] provided in the PV-WAVE language rather than to use a cross-correlation function written by the author. Hence, it was feasible to generate the correlation surface for all template positions. An example of the correlation surface is shown in figure 3.

Figure 3 - Correlation surface

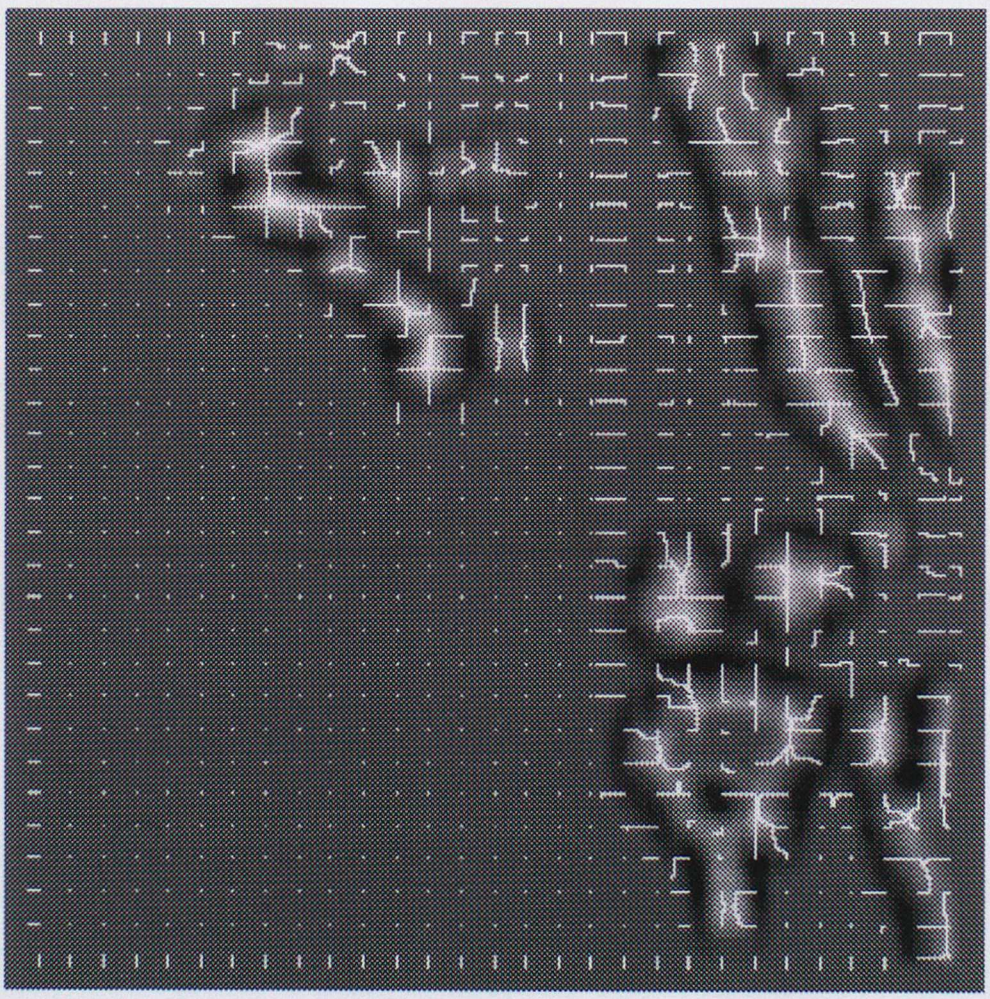


[1] It is necessary to reverse the template "kernel" in the "x"-direction where this was not symmetric laterally.

3.3 Analysis of the correlation surface

The next stage is to identify significant peaks in the correlation surface. This was done using a version of the common "gradient-ascent" method. It can be envisaged as follows. An ant is released at a point on the correlation surface. Being somewhat myopic and rather stupid, he climbs up the steepest gradient in his immediate vicinity, repeating the process until he is either on the top of a peak or until he reaches the edge of the image. Other ants are simultaneously doing the same in other parts of the image. Each successful ant reports back the coordinates of the peak it has found. At the end of the process, all of the peaks have been discovered (at least, at a resolution consistent with that with which the ants were released). Some ants may have discovered the same peak: it is necessary to filter out the multiple references to the same peak. Examples of the paths made by the ants are shown in figure 4.

Figure 4 - "Ant paths" on the correlation surface



With the help of the ants on the correlation surface, a number of cloud elements have been discovered that correspond closely to the shape represented in the template. If we are looking for convective clouds at an early stage in formation, it is appropriate to specify a fairly small circular element in the template. Identifying mature storms would require a larger template. It is also important to ensure that the convolution of the template with a uniform area of cloud (eg a high value) is the same as its convolution with a "clear" area (eg a low value) to prevent the generation of false peaks in the correlation surface within the clouds. This can be done by providing the template with an appropriate "skirt" of negative values.

If the problem in hand concerns the detection of large cumulus clouds, the positions found at the end of this stage would be sufficient, only requiring transformation to geographical coordinates. However, there is a related requirement to delineate areas in which smaller convective clouds are forming.

4 Principle of the "area analysis" method

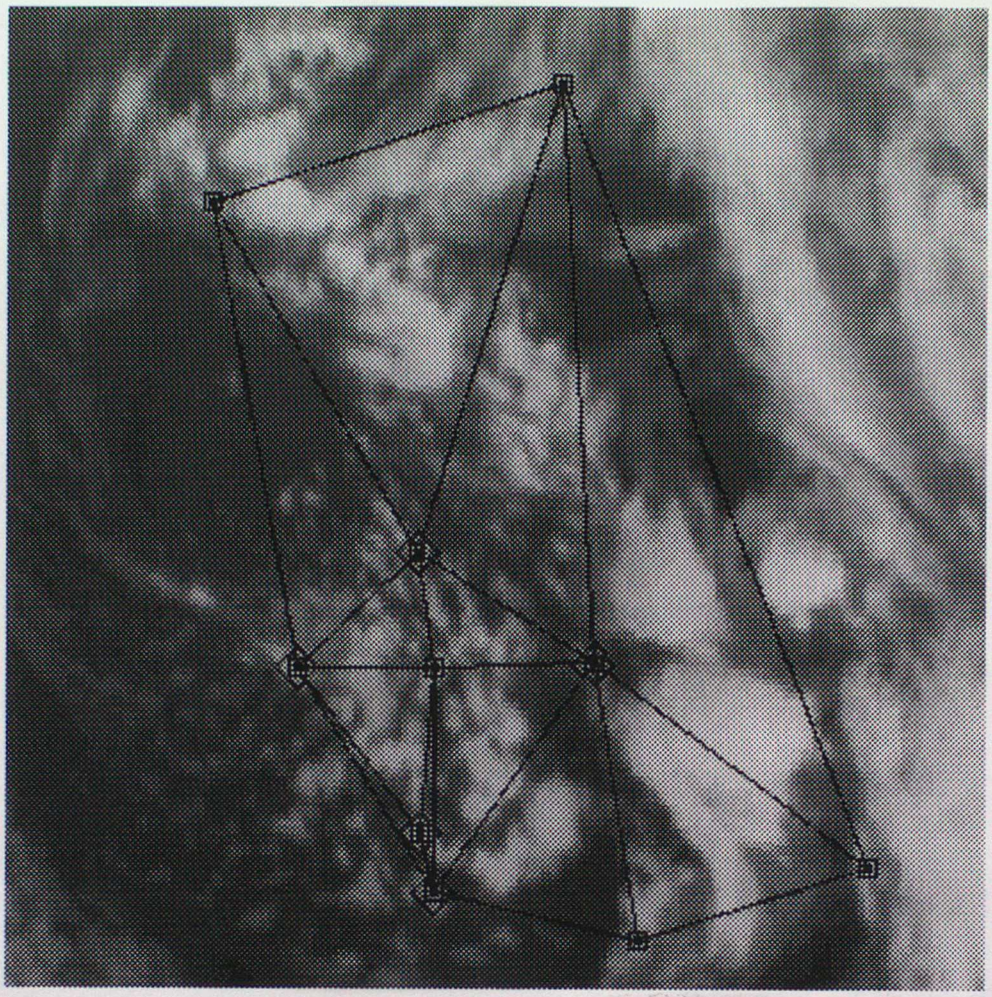
Having identified a number of clouds with desired spatial characteristics, an analysis of their positions relative to one another is performed in an attempt to define areas of convection. This is performed using graph analysis. The scheme works as follows.

Firstly, the positions of the pixels are regarded as Euclidian points in a two-dimensional space: these become nodes of a graph (see eg Wilson (1985), especially chapters 1 and 2). Lines are drawn between nodes such that they do not cross one another. This is done by computing internode lines successively and checking whether each new line intersects an existing one. When two lines are discovered to cross, the longer one is deleted. The resulting graph tesselates the space with triangular tiles, each tile having inter-node lines as its edges. See figure 5.

The lines joining each node in the network are then examined to see if it is likely that the node is at the edge of an area of convective cloud. Such areas are recognised by having a number of relatively closely-spaced small blobs surrounded by blobs that are relatively far away. Nodes are sought, therefore, for which the shortest line joining the node is shorter than a certain length and the range of line lengths is relatively large. Nodes that satisfy both of these criteria are stored in a table.

Secondly, it is necessary to find areas that contain the convective blobs using this subset of the original nodes to define the boundary of the each area, bearing in mind that there may be a number of such areas in the scene. The method used is as follows. A second graph analysis is made using the subset of special nodes. Paths are then traced around the network moving from node to node in an attempt to visit all of the nodes once only and to return to the original node. Paths greater than a certain length are not used in the process, reflecting the greater separation between different areas of convective activity. This can be a highly intensive process computationally, particularly when there are a large number of nodes. Eventually (!) a number of paths might be found that satisfy the above criteria. The required path is the one that surrounds the greatest area.

Figure 5 - IR image with graph linking detected nodes



5 Conclusions

A preliminary scheme for detecting cloud elements of a certain shape, both individually and in groups, has been developed. It seems likely that the former method would be most applicable to the detection of convective clouds that have already grown to a significant size and that the latter would be more useful in identifying large areas of convectively unstable air.

Figure 6 shows an example of the detection of large convective elements. Figure 7 shows an example of the delineation of areas of small convective elements.

Figure 6 - Large cumulus detected in Meteosat image

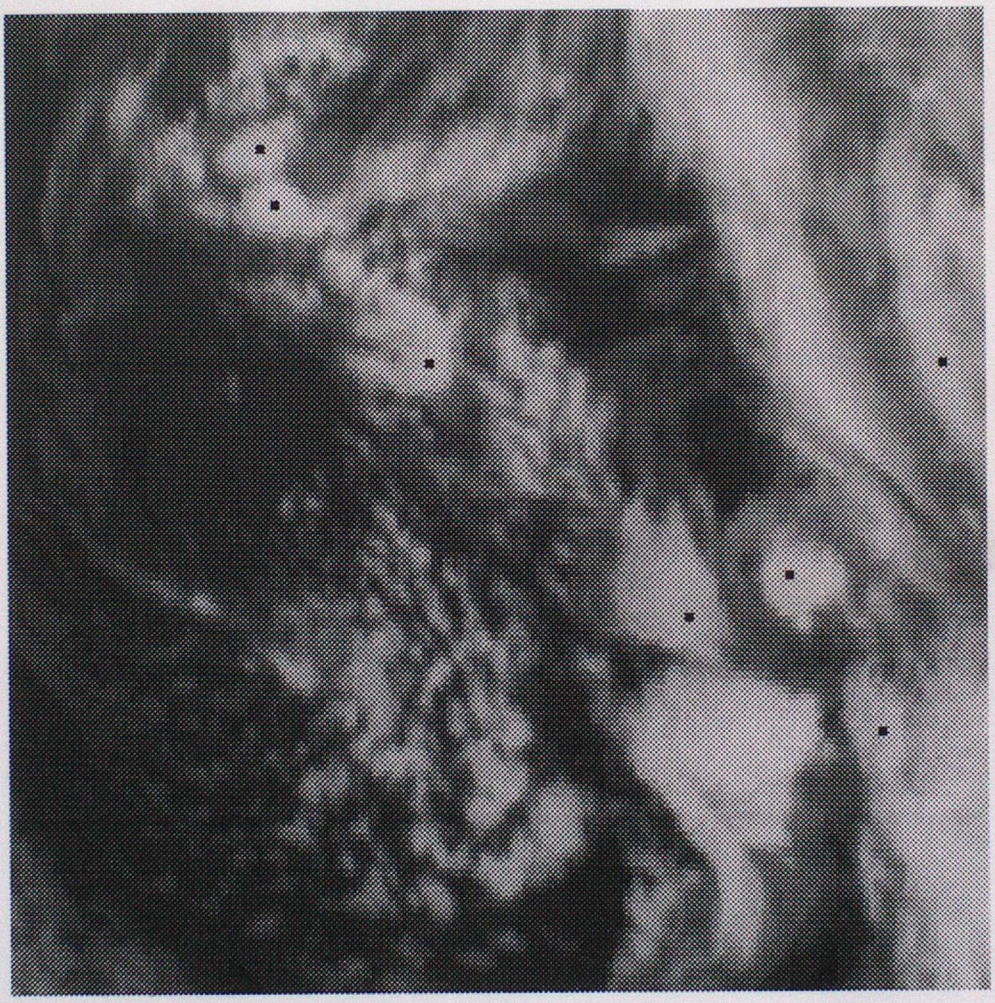
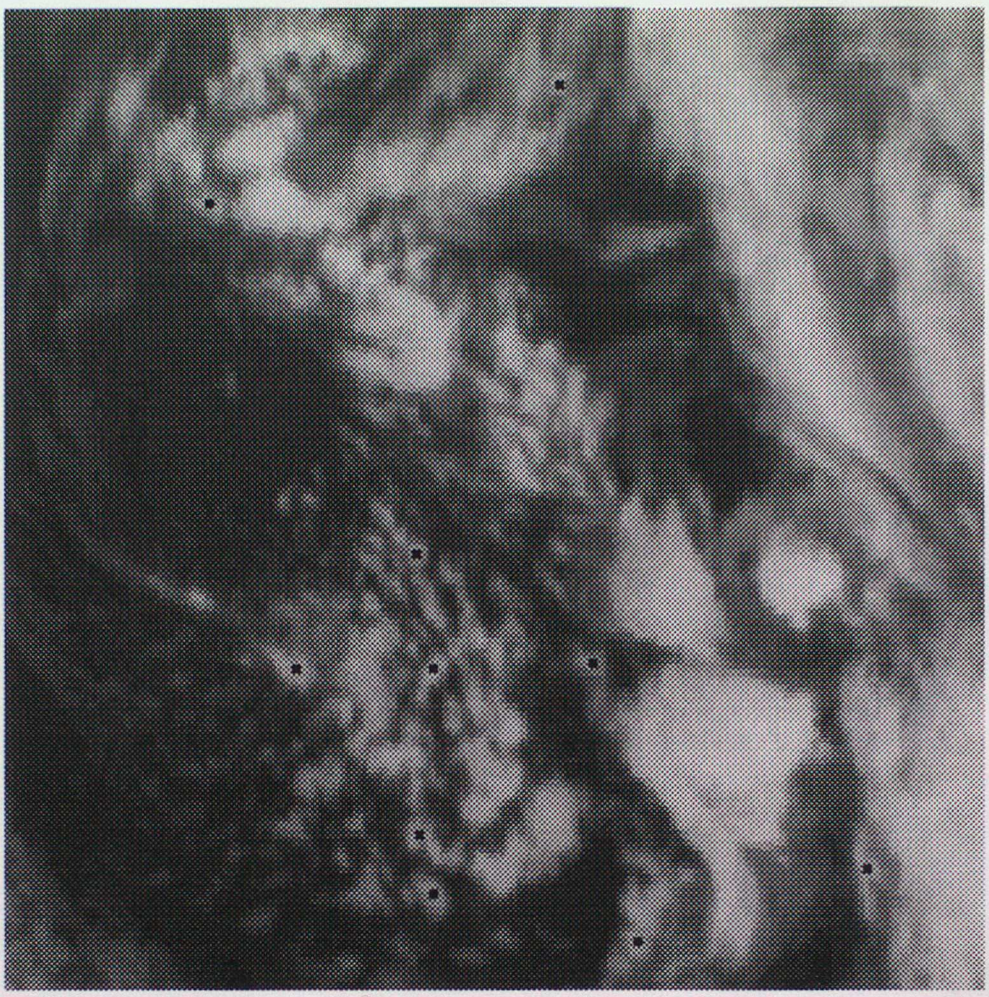


Figure 7 - Smaller cumulus detected in Meteosat image



A number of studies are required to develop the scheme further. The results are sensitive to the initial "slicing" of the original multi-level image, a process intended to delineate areas of significant cloud. A more sophisticated multi-spectral scheme which should yield better results is currently being developed in the Satellite Image Applications Group in (FR). It is also planned to investigate methods of cloud detection that employ artificial intelligence techniques.

The current scheme specifies a single cloud "template" for use in searching for similar features in the image, which limits the method to a single size and shape of cloud feature. It would be straightforward to repeat the analysis using templates of differing sizes in an attempt to define significant features at a variety of scales. The use of the information available at this time could be used to specify more carefully the nodes of the graph to be analysed or to determine more detail about each detected feature.

Some of the processes used in the schemes are computational rather intensive, notably the path-following method used to find the border of an area. This latter problem is related to (but not identical with) the famous "Travelling Salesman" problem, renowned for its complexity (Wilson (1985), pg 41-2). Recent reports have indicated that good approximations to its solution can be found using neural network techniques that are very much more efficient

than the exact solution used in the current scheme. Perhaps similar methods might be applicable here too.

6 References

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